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MANNED SPACECRAFT CENTER VIEWPOINTS ON RELIABILITY AND QUALITY CONTROL*

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The quality control requirements and procedures that are being developed for manned spacecraft differ in a number of important respects from the conventional practices that have evolved in previous aircraft and missile programs. These differences are a natural consequence of some of the distinctive features of manned space flight programs and vehicles. In my remarks tonight I will attempt to point out a few of these distinctive features and their effect on reliability and quality control requirements.

The most outstanding feature of our programs is their research character. The flight missions being undertaken in the manned exploration of space are in every sense of the word research flights. They are a search for knowledge, not only of space itself, but also on how to survive, travel, and maneuver in space; to take off and land spacecraft on the earth, the moon, and eventually the planets.

The spacecraft we use are single-purpose devices, few in number, tailored specifically to each particular mission. Once the mission for which they are designed has been accomplished, they are unlikely to enter a production phase or enjoy a long period of

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operational use as might a missile or airplane. In this sense, our quality control problems are much closer to those of the X-15 than to those of the B-58.

For those few pioneering spacecraft we must obtain parts, components, subsystems, and engineering as near to perfection as the nation's finest craftsmen can achieve.

The single-purpose character of our spacecraft is not exactly of our own choosing. Nature has perversely laid out the stepping stones to space in such a way as to require a substantial advance in propulsion capability between each step. An urgent need for tangible evidence of progress in space impells us to attempt each step as soon as the minimum capability can be achieved. Because we are undertaking successive missions as rapidly as possible, always at the extreme outer limit of our advancing propulsion capability, the spacecraft we use are rightly weight limited. They can never be provided with the growth potential that would allow them to be adapted to succeeding steps. Nor can the experienced engineering team completing the crucial final flight stages of one program be safely diverted from its task to undertake the design of the vehicle. Thus, we must progress by a series of more or less independent programs, each of increasing size and complexity, overlapping in time, and manned by different independent teams of government and contractor engineers, each having little if any first-hand familiarity with the most recent manned space flight experience available at the time the program starts. This situation obviously calls for strong emphasis or rapid dissemination of operational experience with spacecraft systems throughout the entire management, engineering, industrial, and educational complex. No matter how hard we work on this approach, however, we cannot hope to achieve perfection. Some design decisions will still be made in ignorance of information that exists, and others will be shown wrong by information yet to be acquired. These errors will have to be corrected before flight. Thus we arrive at what is perhaps the most important single requirement in our programs; that designs, procedures, and schedules must have the flexibility to absorb a steady stream of changes generated by a continually increasing understanding of space problems. Reliability, quality control, manufacturing, and procurement plans must all be set up with full recognition of this requirement for continual hardware change.

The flow of new information from current space programs is not the only source of requirements for change. Equipment malfunctions that occur during system development testing or preflight preparations are often of equal or greater importance. In manned flight we cannot afford to regard any of these equipment malfunctions as a random failure. We must regard every malfunction and, in fact, every observed peculiarity in the behavior of a system as an important warning of potential disaster. Only when the cause is thoroughly understood, and a change to eliminate it has been made, can we proceed with the flight program.

The problem here is one of shortening the failure detection---corrective action cycle to eliminate disastrous effects on operating schedules. We are finding it necessary to require very drastic streamlining of procedures that have grown up in mass production programs, where action seldom starts until a failure has been repeated at least enough times to accumulate a noticeable pile of IBM cards, and where the subsequent paper-lined path from prime contractor, to subcontractor, to parts vendor, and back, too often produces little but delay, cost, and disclaimers of responsibility.

Rapid corrective response to malfunctions throughout system development and preflight preparations is a critically important requirement of our programs if we are to meet schedules with hardware that is fit to fly. To the maximum extent possible, failure analysis and decisions as to corrective action must take place immediately at the scene of the failure, where the availability of the part, the test set-up, and the people involved in the test, offers the best opportunity for accurate determination of the pertinent facts. Contracts and purchase agreements with component and parts suppliers should provide that the services of their engineering staffs will be available on call whenever required for this purpose. Constructive and effective reaction to the emergency situation created when a failure requires redesign of a spacecraft component is the most welcome contribution an individual or company can make to the nation's space programs.

Another distinctive characteristic of our spacecraft is the large number of one-shot and limited-life items used in the various subsystems. This characteristic limits the amount of proof testing that can be performed on the actual flight articles. In the case of items such as the heat shield, escape rockets, explosive separation devices, explosive disconnects, igniters, etc., the actual specimen to be flown cannot be tested at all. Items such as fuel cells, ablative nozzles, parachutes, and launch vehicle engines can be given only limited tests, under conditions that are not truly representative, and then only at considerable risk that the tests and their aftermath may introduce more flight failures than they prevent. This particular problem is of course shared by the ballistic missile but not by the airplane.

The operating philosophy that has evolved to meet the situation is based on the idea that randomly selected samples of components can be subjected, in a so-called qualification test program, to appropriate environmental, reliability, and overstress tests with complete confidence that the results of these tests will apply to the remaining articles installed in the flight vehicles. This confidence is not justified unless all supposedly identical parts from which the components are assembled are truly identical in all essential features. Although the parts can be inspected and their primary characteristics can be measured, identity in the sense required by the qualification test philosophy cannot be fully established by inspection and measurement alone. Features that eventually turn out to be important in governing sensitivity to environment or susceptibility to failure often are unrecognized or inadequately defined by inspection or measurement at the time of manufacture.

To achieve a degree of control over whatever unknown or indeterminate influences may exist, consideration must be given to the necessity that all components requiring certification through a qualification test program be made up from sets of parts whose members have been produced consecutively on the same assembly line without an intervening change in design, process, or materials. Handling subsequent to manufacture must also be identical and must be controlled to hold environmental stresses well within the limits to be experienced by the part during the qualification tests. It is also necessary that the parts be identified individually or as members of the set and that records show the location of all parts in a set.

This requirement for identification of parts is of critical importance whenever failure of a component under test reveals a defect in a part which can be attributed to the design or to the manufacturing or handling process. It then becomes essential to locate and remove immediately from all flight components all similar parts. Since these parts may have been used in more than the one type of component that revealed the deficiency, it is not sufficient merely to remove all of that type of component. The very strict control over parts identification and use that we are seeking is necessary to insure that all suspected parts, whenever used, can be readily located for removal and replacement.

In the area of inspection, flight safety considerations and the limited number of articles involved in our programs make it reasonable to require 100 per cent inspection of all items. Inspection procedures must be designed to locate and reject every defective or marginal part, no matter how many good parts are unnecessarily rejected in the process. We are not alone in this matter of extreme selectivity in the acceptance of parts for spacecraft. In the outstandingly successful Telestar satellite 58,800 acceptable solid state devices were examined to select the 22,500 for the 7 flyable models.

Another indication of what can be accomplished by selectivity combined with persistent attention to detail has been provided by the program devised by the Air Force and the Aerospace Corporation for the selection and preparation of the Atlas boosters for manned Mercury flights. Recognizing that major design changes to increase the reliability potential of the basic design could not be accomplished within the life of the Mercury program, they set out to make certain that the maximum reliability of which the design was capable would actually be achieved in Mercury operations. The program that resulted involved three parts, a Component Selection Program, a Factory Rollout Inspection Program, and a Flight Safety Review Program at the launch site.

In the component selection program all available Atlas components were screened. Those whose prior history and performance under test were closest to ideal were selected and reserved for manned Mercury flights.

In the factory rollout inspection program technical teams of Air Force and Aerospace experts on each booster subsystem were set up to review the manufacturing history and factory tests of each Mercury booster to verify and certify its suitability for manned flight.

In the flight safety review program similar technical teams were organized at the launch site to monitor and record the performance of each subsystem throughout all preflight preparations and checkout activities. These teams reported to a senior review board charged with the final responsibility for reviewing all the problems and actions pertinent to the booster and certifying that, within the limits of human knowledge, it was ready for manned orbital flight.

As a result of this program, the Mercury boosters have required twice the normal man-hours to fabricate, and have received more than three times the normal checkout time and attention. While no man can say that this formula insures success, it certainly does not invite failure.

In the case of the spacecraft, we have followed a generally similar approach as regards technical surveillance and review of subsystem performance. Special emphasis has been placed on maintaining a particularly high level of technical capability at the launch site, and on very thorough investigations of every sympton of trouble during the rather extensive preflight preparation. A basic ground rule of the operation has been that the spacecraft cannot be committed to flight while any observed difficulty remains unexplained or uncorrected.

We believe these operating procedures developed for the Mercury booster and spacecraft have been very effective in concentrating the attention of the best qualified technical talent available on the detailed engineering problems of each vehicle. Similar procedures will be followed in our future programs.

In the design and testing areas our approach to the reliability and flight safety problem also reflects lessons learned in previous research airplane, missile, and space flight programs. While we attempt to augment safety wherever practical by emergency escape provisions, we recognize that the most effective approach to safety is through vehicle reliability.

To insure that adequate attention is directed to reliability in the design stage we specify an overall numerical reliability goal for the spacecraft. This overall goal is subsequently budgeted to the various subsystems by the spacecraft designer. These numerical reliability requirements are very useful in the design stage because they give the subsystem designer a rational basis for deciding on the degree of redundancy, derating of parts, and other reliability improvement measures that should be incorporated in his subsystem.

In estimating the reliability of a proposed subsystem design, use must be made of failure rate data or estimates for the individual parts that make up the subsystem. These failure rate estimates normally include only the so-called random or statistical type of failure that predominates in fully developed parts. Hence, subsystem and spacecraft reliability values derived in this way tend to reflect the minimum failure rate that may ultimately be obtained with the design. The actual subsystem failure rates may initially be much higher because of design errors, interaction effects between parts and components, unanticipated environmental effects, or errors in estimating environments. Virtually all of our flight difficulties to date have been in this subsystem development category. Most would have been detected and eliminated before flight if the ground test techniques and programs that were ultimately devised had been available at that time. As a result of this experience, we are tending to concentrate much of our reliability effort on devising subsystem test programs that will detect and eliminate these avoidable sources of failure before flight.

Basically, our approach is an attempt to lay out system designs that will absorb the expected number of parts failures without serious consequences, and to lay out a testing program that will assure detection and correction of all other sources of system failure before flight.

The last and most fundamental requirement for success in our manned space effort is for the kind of people who will not permit it to fail. In the final analysis there are very few failures in the history of flight that could not have been avoided, if someone, somewhere, had been more experienced, more skillful, more careful, or more highly motivated. To design, build, and operate the vehicles that will pioneer the exploration of space requires the services of the most capable and most experienced people and companies of the Aerospace Industry people whose pride in their craftsmanship will permit no compromise of the quality essential to success; people who will never overlook or ignore the slightest sign of trouble; people who will freely give that last bit of extra effort that so often spells the difference between success and failure.

The requirements for reliability and quality that I have been discussing this evening are perhaps best summarized in the simple basic philosophy from which they derive: that every manned spacecraft that leaves this earth on the most ambitious and challenging adventure in human history shall represent the best that dedicated and inspired men can create. We cannot ask for more; we dare not settle for less.